Journal of the Royal Society of Western Australia, 77: 151-158, 1994

The impact of plant disease on mining

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Abstract

Dieback disease caused by *Phytophthora* species is the only plant disease having a major impact on the bauxite mining operations of Alcoa of Australia Ltd and the mineral sands mining operations of RGC Mineral Sands Pty Ltd. To mine responsibly in regions of the state where dieback is a concern, both companies have implemented major dieback management programs. The financial costs associated with implementing these programs are substantial. However, estimating the total financial cost of dieback disease management on the mining operations is very difficult because dieback control procedures are integrated with mine planning and other operational procedures. Both companies recognise that these financial costs are part of the overall cost of mining in regions of Western Australia where dieback is present, and conservation of the natural vegetation communities is of high priority.

Financial considerations are not the only potential impacts of disease. Plant diseases can also impact on environmental management objectives. Dieback disease has the potential to affect three important environmental management objectives; protecting the adjacent natural vegetation, establishing key plant species in rehabilitated sites, and achieving high species richness in these sites. Achievement of these objectives is regarded as important to the success of the mining operations of both companies.

Alcoa and RGC monitor vegetation adjacent to their mining operations and rehabilitated areas for symptoms of dieback. There has been no *Phytophthora*-caused plant death found near RGC's operations in areas interpreted previously as uninfested. Monitoring of the forest surrounding a 120 ha bauxite mined area identified two new *P.cinnamomi* infestations; the total area was 0.32 ha. Establishment of key plant species in the rehabilitation (*Eucalyptus marginata* in the jarrah forest and *Banksia species* in the kwongan) has been successful despite the presence of *Phytophthora* species in the region. High species richness is achieved in the rehabilitated areas of both operations. Long term monitoring and continued research are still required on many aspects of this disease.

By developing dieback control procedures based on scientific knowledge of the pathogen and the disease process, and integrating these procedures with routine mining procedures, we believe both companies have successfully minimised the impact of their mining operations on surrounding and re-established native vegetation communities.

Introduction

Plant disease has a major financial impact on the mining operations of Alcoa of Australia Limited and RGC Mineral Sands Limited. However, there is more to impact than just financial considerations. Evaluation of the impact of disease on mining also needs to assess the impact of disease on the environmental management objectives of both companies. Achievement of these objectives is regarded as important to the overall success of the mining operations.

The only plant disease having a significant impact on Alcoa and RGC is dieback disease caused by *Phytophthora* species. This disease is a major threat to the native plant communities in the regions of Western Australia where both companies mine. Environmental management objectives have been developed for the mines; their focus is to protect the natural communities surrounding the mine and to create an ecosystem on the mined areas with vegetation similar to that which occurred before mining. The presence of dieback has the potential to prevent these objectives being achieved.

The aim of this review is to discuss both the financial impact of disease on Alcoa and RGC mining operations and the potential impact of plant disease on the environmental objectives of both companies.

Background to mining operations

Alcoa operates three bauxite mines in the jarrah forest, south east of Perth (Fig 1). Alcoa mines and rehabilitates an average of 450 ha of forest a year. Bauxite ore bodies tend to be on the mid to upper slopes and are of the order of 5-50 ha. The open cut mining procedures remove the hard laterite "caprock" and the more friable zone below the caprock. The depth of mining is usually between 3 and 5 m. Following mining the area is landscaped, the surface soil is returned and the area is ripped to remove compaction. Finally, the area is seeded with about 50 species of plants indigenous to

Symposium on Plant Diseases in Ecosystems: Threats and impacts in south-western Australia.
Held on April 16, 1994, at Murdoch University, by the Royal Society of Western Australia and the Ecological Society of Australia.

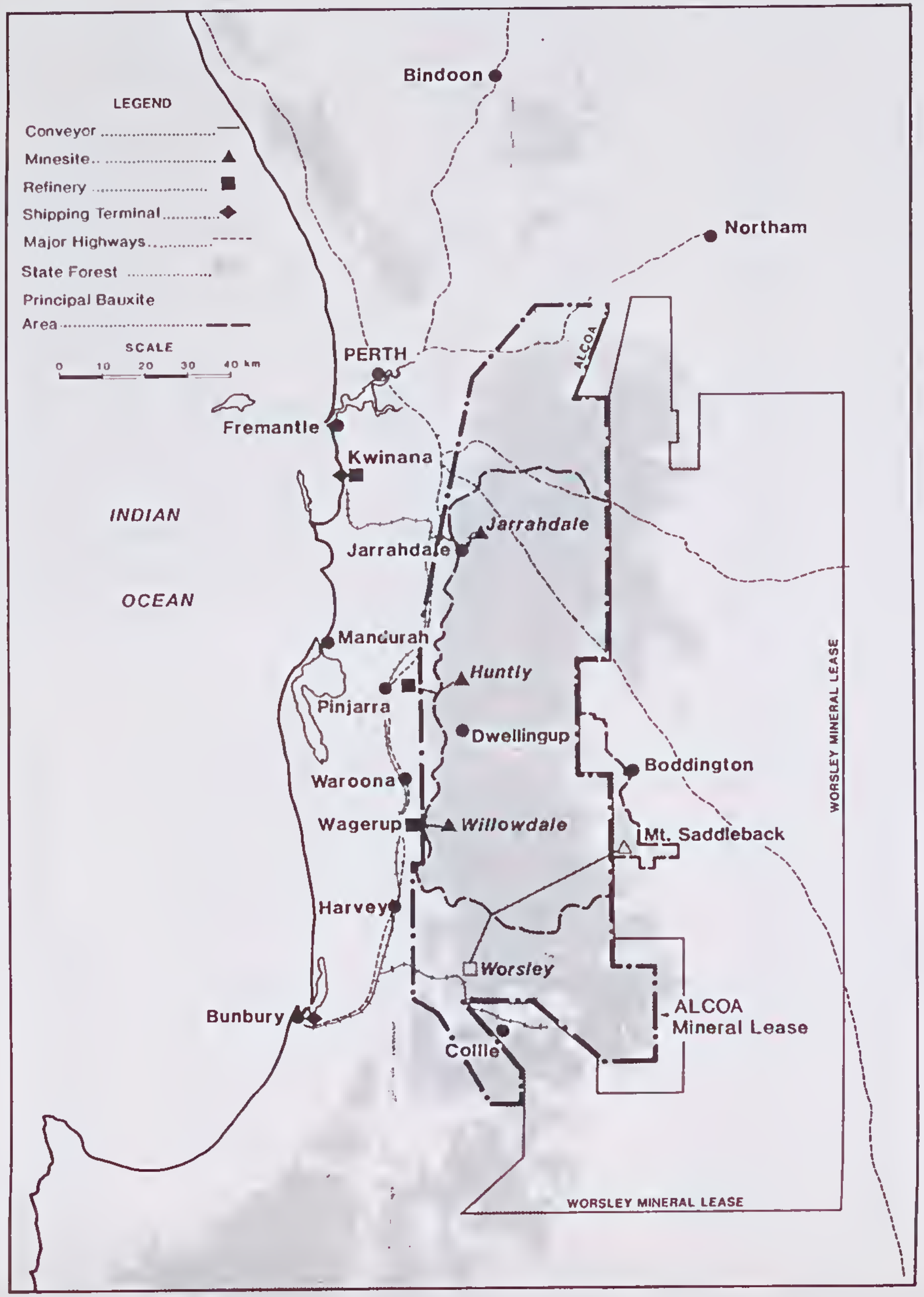

Figure 1 Location of Alcoa's operations in Western Australia

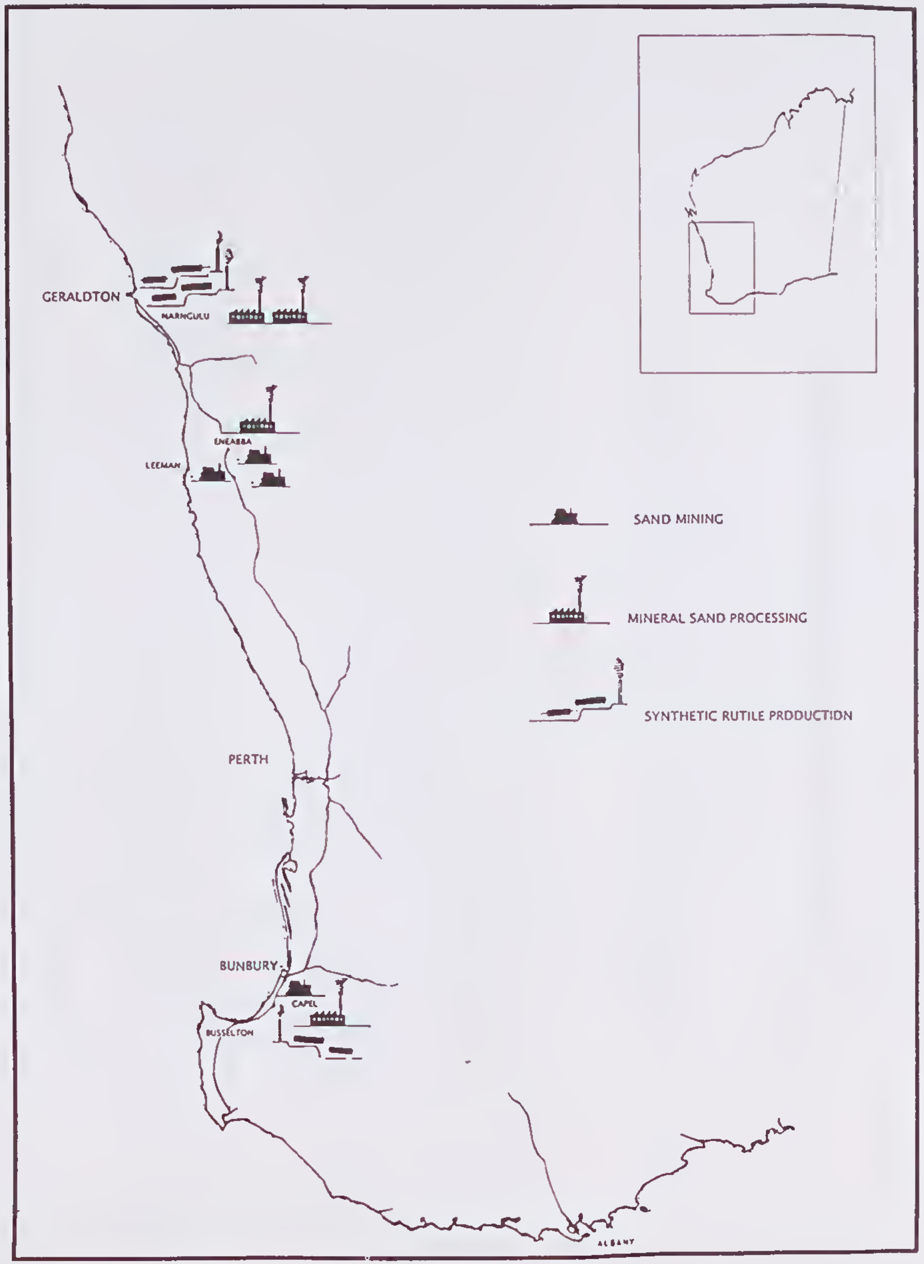

Figure 2 Location of RGC's operations in Western Australia

this region of the northern jarrah forest. Jarrah is established as the dominant tree species. The overall aim of revegetation is to create a community similar to the one present prior to mining. The mining and rehabilitation procedures are described in more detail by Nichols *et al.* (1985) and Ward *et al.* (1993). All mines are located in the western, high rainfall region of the jarrah forest where the extent of *P. cinnamomi* infestation is considerably greater than the estimate of 14% derived for the entire jarrah forest (Davison & Shearer 1989). *P. cinnamomi* infestation ranges from 66% of the forest at the Willowdale mine to 33% at the Huntly mine.

RGC mines and processes mineral sands to produce ilmenite, rutile and zircon. Its largest operations are near Eneabba on the Swan Coastal Plain about 300 km north of Perth and 30 km inland (Fig 2). Currently two mines are operating. One mine is a dredging operation whilst the second uses trucks, scrapers and other conventional dry mining equipment. The ore bodies are located underneath native heathland (kwongan) and agricultural land. The distribution of ore tends to follow long thin "strands" (*e.g.* 10 km long, 120m wide and 30m deep). Once the ore is mined, the heavy mineral is removed by wet gravity separation using water. The non-mineral slurry is pumped back to the mined-out pits where it is left to dry before it is landscaped, topsoil returned and revegetated. In the species-rich kwongan, the rehabilitation objective is to establish a self sustaining ecosystem similar to the undisturbed heath. Premining surveys recorded 429 species from 50 families and 162 genera. Many of the principal genera are susceptible to *Phytophthora* species.

Plant diseases

Dieback disease caused by *Phytophthora* species is the only plant disease having a major impact on the mining operations of Alcoa and RGC. The term 'dieback disease' is used here exclusively to describe the diseases of native plants caused by *Phytophthora* spp, where infection leads to a 'root rot' or 'collar rot', and the eventual death of the plants. The earliest records for this disease in Western Australia came from the jarrah forest where there were unexplained deaths of jarrah trees in the early 1920s. The association between the deaths of jarrah and infection by *P. cinnamomi* was established in the mid 1960's (Podger *et al.* 1965, Podger 1972). Although this disease in the jarrah forest is commonly called 'jarrah dieback', it is known that many other species are susceptible to *P. cinnamomi* in a range of vegetation communities (Shearer & Tippett 1989, Shearer 1990).

Phytophthora cinnamomi is the most destructive of the seven species of *Phytophthora* found in south-western Australia. It is the only species having a significant impact on the mining operation of Alcoa (Colquhoun 1992) and it is the cause of most *Phytophthora* related deaths in the northern sandplain around the RGC mine. However, *P. citricola*, *P. megasperma* var *megasperma*, and *P. megasperma* var *sojae* are also known to have caused plant death in the northern sandplain (Hill 1990).

All of these *Phytophthora* species are soil borne and spread readily in soil and water. During mining, huge volumes of soil are transported, large road networks are established and the drainage of areas is altered markedly. All Western Australian mining companies working in *Phytophthora*-infested areas recognise that mining has the potential to spread the pathogens and thereby increase the area of infestation. The need for dieback control measures is also recognised by the companies. Alcoa and RGC have developed and deployed intensive dieback management programs to minimise the potential to spread the pathogens to native communities and rehabilitated mined areas. The dieback management programs are based on an understanding of the pathogen and the disease process. This understanding was gained from scientific studies; many of these were undertaken by local research institutions and funded by West Australian mining companies.

There is a range of other plant diseases which are having an impact on mining operations, but the impact is minor in comparison to dieback disease. A range of canker fungi have been isolated from plants growing in rehabilitated bauxite mined areas. The fungi identified include *Botryosporuim* spp, *Botryosphaeria ribis*, *Cytospora eucalypticola* and *Pestalotioposis* sp (Carswell 1993). Only on a few occasions has the presence of these fungi been linked to the death of a plant in the rehabilited areas. *Armillaria luteobubilina* is found frequently in the jarrah forest. Forest sites infested with this pathogen have been mined and the soil used in rehabilitation. Despite regular monitoring of deaths of plants in rehabilitation, and field reconnaissance of most rehabilitated pits, there has been no report of multiple deaths from this pathogen.

Alcoa and RGC operate nurseries which propagate native plants for use in the mine rehabilitation program. The control of plant diseases caused by species of *Phytophthora*, *Rhizoctionia*, and *Pythium* is critical to successfully producing container grown plants. Both Alcoa and RGC nurseries have been successfully accredited by the Nursery Industry Association of WA as meeting the required standards of *Phytophthora* disease control.

Two of the most important plant families in the Northern Sandplains are the Restionaceae (rushes) and Cyperaceae (sedges). Previous research had shown that most rush and sedge species in the Northern Sandplains are affected by smut diseases. These diseases may cause up to 100% reduction in seed set and reduce seed quality in many species. Smut-affected populations have been shown to have a significantly reduced capacity to recruit seedlings, particularly where the parent plants are killed by fire. Plants of a number of species become chlorotic and senesce following infection by smut diseases. Research work is currently being funded by RGC and conducted by Kings Park Board on controlling smut in rushes and sedges so that improvements can be made in their rehabilitation and the impact of these diseases is lessened.

The financial impact of dieback on mining

The dieback management programs of Alcoa and RGC are a major cost to the operations. Dieback control measures are present at virtually all stages of mining. Some major costs are easy to determine (Table 1) but the greatest will be the "hidden" costs associated with the day-to-day operations of the mines. Many stages of mining now take longer and require increased use of machinery. To minimise the disruptions to mining, the control measures have been integrated with the routine mine planning and operational procedures. Due to this integration the total financial impact is very difficult to determine.

Table 1
Major costs associated with Alcoa and RGC dieback management programs

	ALCOA $	RGC $
Construction of vehicle cleaning facilities	300,000	300,000
Dieback interpretation and mapping	200,000 per year	20,000 per year
Mapping site vegetation types	220,000 every 5 years	Not applicable
Dieback research funding of external projects	210,000 per year	10,000 per year

Rather than attempt to determine the cost of the dieback management programs for each company, we have provided an overview of the dieback management strategy used by RGC, and a comparison of one stage of bauxite mining with and without dieback control measures. These examples will demonstrate the complexity of dieback management and its associated costs.

Dieback management strategy - RGC

RGC has implemented a dieback management program that addresses hygiene practices, surveys, rehabilitation techniques, drainage patterns, education, research and regular reviews. Some key components of the strategy are:

- mapping the presence of dieback on and around the mining;
- advising all contractors, carriers and personnel of their obligations under the dieback management program;
- ensuring that all vehicles and equipment entering and leaving the site are clean of soil and plant material, by inspection and authorisation from suitably trained personnel;
- providing appropriate washdown and inspection facilities;
- constructing new roads and upgrading existing roads to dieback control standards *e.g.* developing a hard road surface and constructing roads above ground level;
- liaising with the Department of Conservation and Land Management, land owners and other authorities to control unauthorised access;
- developing procedures for movement of vehicles and equipment between sites and locations;
- segregating soil from dieback and non-dieback areas; and
- supporting research to increase the understanding of the disease and to develop improved dieback control measures.

Alcoa employs a similar dieback management strategy. As part of this strategy, Alcoa has developed detailed dieback control measures for each stage of mining.

Dieback control measures associated with overburden* removal and storage - Alcoa

During this phase of bauxite mining, all of the overburden is stripped from the orebody (using scrapers) and stored in large stockpiles. Following mining and landscaping of the minepit this overburden is returned to the area. Without dieback control measures, the process is simple; the scraper traverses the orebody in the most efficient manner to remove the overburden and transports it to a stockpile. The stockpile is usually located at the edge of the orebody, in the most convenient position for the operations (Fig 3a).

With the application of the current dieback control measures for stripping overburden at the Huntly mine, the operating procedures now involve (see Fig 3b):

- mapping for the presence of dieback (approx. 10,000 ha for 10 years of mining at one mine);
- marking the dieback boundary in the field. This boundary tends to split the orebody into "dieback" and "dieback-free" areas;
- surveying the boundary lines and recording these on a geographical information system (GIS) for use by mining and environmental planners;
- stripping the "dieback" and "dieback-free" overburden separately;
- ensuring that all vehicles moving across the dieback boundary into the "dieback-free" area are free of infested soil. Vehicle cleaning stations are located on the boundaries;
- storing the "dieback" and "dieback-free" overburden in separate stockpiles;
- selecting stockpile locations where the risk of spreading *P. cinnamomi* and the risk of increasing the impact of the pathogen in the infested forest is minimal. This generally results in the "dieback-free" stockpiles being constructed in a previously mined area, where the risk of water draining from the stockpile into the uninfested forest is prevented, and
- where necessary, increasing the vertical infiltration of water of the site selected for the stockpile. This usually involves blasting the rock layer on and downslope of the future stockpile area.

The impacts of dieback control procedures on the day to day operations of removing and storing overburden are manifest; the procedure takes longer, requires more environmental monitoring, requires more resources (scrapers, drill rigs from blasting, surveyors, GIS operators, *etc.*) and requires more education and training of the operators and planners. This level of intensity of dieback control is achieved at all stages of bauxite mining and rehabilitation.

To collate the "hidden" costs associated with dieback management for RGC and Alcoa would be a complex and arduous task, and we do not believe that this is necessary. Both companies recognise that these financial costs are part of the overall cost of mining in the region of Western Australia where *P. cinnamomi* is present and the conservation of the natural vegetation communities is of high priority. How-

* Overburden is the part off the soil profile above the ore layer, which remains after the topsoil (top 15 cm of the profile) has been removed. The nutrient level and seed load is low in the overburden so this soil is stockpiled and returned during the rehabilitation phase.

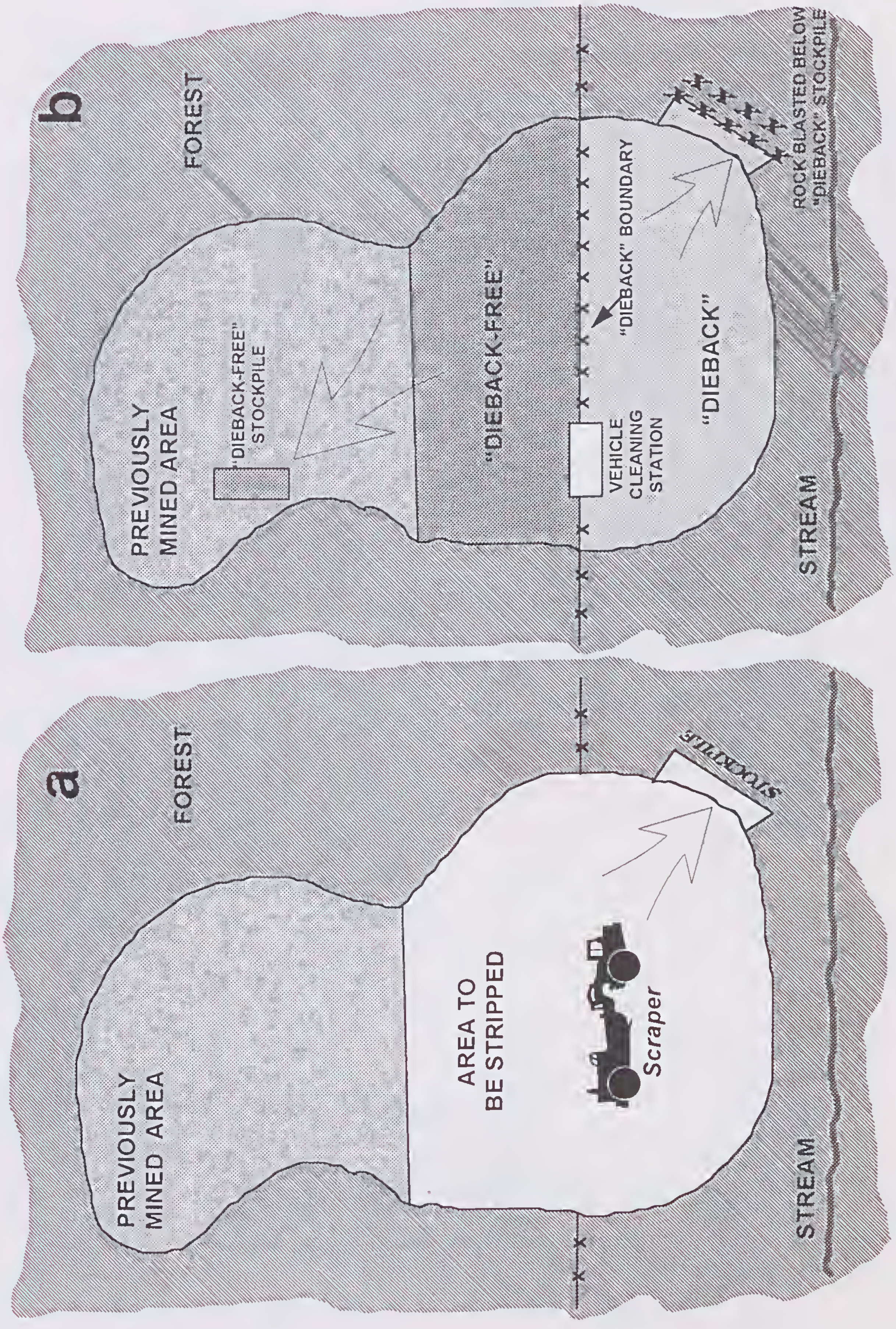

Figure 3. Schematic of the operation of stripping overburden from a bauxite ore body, (a) without dieback control measures and (b) with dieback control measures.

ever, research and development work continually aims to develop more effective and less expensive procedures.

Impact of dieback on environmental objectives

Dieback has the potential to adversely affect three important objectives for the environmental management of the mining leases:

- protect the vegetation surrounding the mined areas,
- establish key plant species in rehabilitated mined areas, and
- achieve high species richness in rehabilitated mined areas.

Protection of the adjacent natural vegetation

This environmental management objective is to prevent mining from causing significant adverse effects on natural communities near the mines. The spread of *Phytophthora* species to these sites has the potential to have a major impact on the health and species composition of these areas. Consequently, a critical aim of all dieback management programs is to prevent the spread of the pathogen to uninfested, natural communities. Control measures are introduced to minimise the risk of infested soil or water being deposited in these areas.

At Alcoa, attempts are being made to quantify the level of spread of *P. cinnamomi* that can be directly related to mining operations. The procedure involves identifying pits where the adjacent forest was uninfested before mining then remapping for dieback symptoms after rehabilitation. The increase in the area of infested forest is then calculated. Any new infections found abutting the pit edge would, in most instances, be attributed to mining. This procedure has been applied to an area at the Huntly mine that received the current intensive dieback control measures. This large mine pit was mined from 1986 to 1990 and rehabilitated in 1991 and 1992. The total area mined was 120 ha and 13.5 km of the pit edge abutted forest interpreted as "dieback free" before mining. The re-interpretation of the pit edge in 1993 identified two new infections; the total area of the new infections was 0.32 ha. This is 0.23% of the area cleared for mining.

Monitoring of the spread of the pathogen provides information on the impact of mining on the adjacent community; it also provides vital feedback on where and how the pathogen is being spread. This feedback is used to improve the dieback control procedures and their implementation.

At RGC the natural vegetation communities around the orebody are inspected regularly. There has been no *Phytophthora*-caused plant death found near the mining operations in communities previously interpreted as uninfected.

The protection of native communities is an important part of environmental management of most mining operations. The measured spread of *Phytophthora* species to these communities is very low but we believe that some long term monitoring is required to ensure that the companies' environmental objectives continue to be achieved.

Establishment of key plant species

The establishment of particular plant species is regarded as important to the success of mine rehabilitation in the jarrah forest and kwongan. In the jarrah forest the key species is jarrah and in the kwongan the dominant *Banksia* species are regarded as key species. All of these key species are susceptible to *Phytophthora* species

Alcoa and RGC mine *Phytophthora*-infested areas so, irrespective of dieback management programs, *Phytophthora* species will be present in some of the rehabilitated areas. Will the presence of *Phytophthora* species prevent the establishment of these key species?

The objective of re-establishing a forest dominated by jarrah after bauxite mining was not considered in the early years of mining. It was assumed that the presence of *P. cinnamomi* would kill the trees. However, in 1978 and 1979 jarrah was established at two mines. In 1986, trials were established at all mines to assess the establishment of jarrah from broadcast seeding. The success of this trial, and high survival of jarrah trees established in earlier revegetation, led to jarrah being re-established as the dominant tree species in most rehabilitated sites after 1987, and all sites after 1991.

Phytophthora cinnamomi has been isolated from dead jarrah plants and soil in rehabilitated mined areas but survival of jarrah is high in both the infested and uninfested sites (Fig 4). The present target for jarrah establishment is 2000 trees ha^{-1} after 9 months. The eventual stocking density of these sites is expected to be similar to a fast growing regrowth forest site *i.e.* 300-500 trees ha^{-1}. In 1993 the mean stocking density of jarrah in 32 rehabilitated pits, 9 months after seeding, was 2790 trees ha^{-1}. Only two pits had less than 1500 trees ha^{-1}.

So despite the presence of *P. cinnamomi* in rehabilitated areas, the early stocking rates are high and the present rate of mortality of jarrah in the rehabilitated areas is low. A cooperative research program with CALM, Murdoch University and Edith Cowan University is identifying and propagating jarrah plants that are known to have a high resistance to *P. cinnamomi*. Another major research program has been initiated to gain a better understanding of the factors affecting the survival of jarrah in revegetated bauxite mined areas. These programs should lead to greater certainty on the long term survival of this key species.

At Eneabba, *Banksia hookerana, B. attenuata, B. leptophylla* and *B. candolleana* are propagated in the company nursery and planted into the rehabilitation. Successful rehabilitation has been achieved despite these species being very susceptible to *Phytophthora*. The banksia seedlings are not planted in high risk areas such as drainage lines. This mimics the natural situation where banksias are usually restricted to the dune ridges and slopes and are not found in seasonally wet depressions.

The results of the monitoring programs suggest that *Phytophthora* species are not having a major impact on the establishment of key plant species in the revegetated mineral sand and bauxite mined areas.

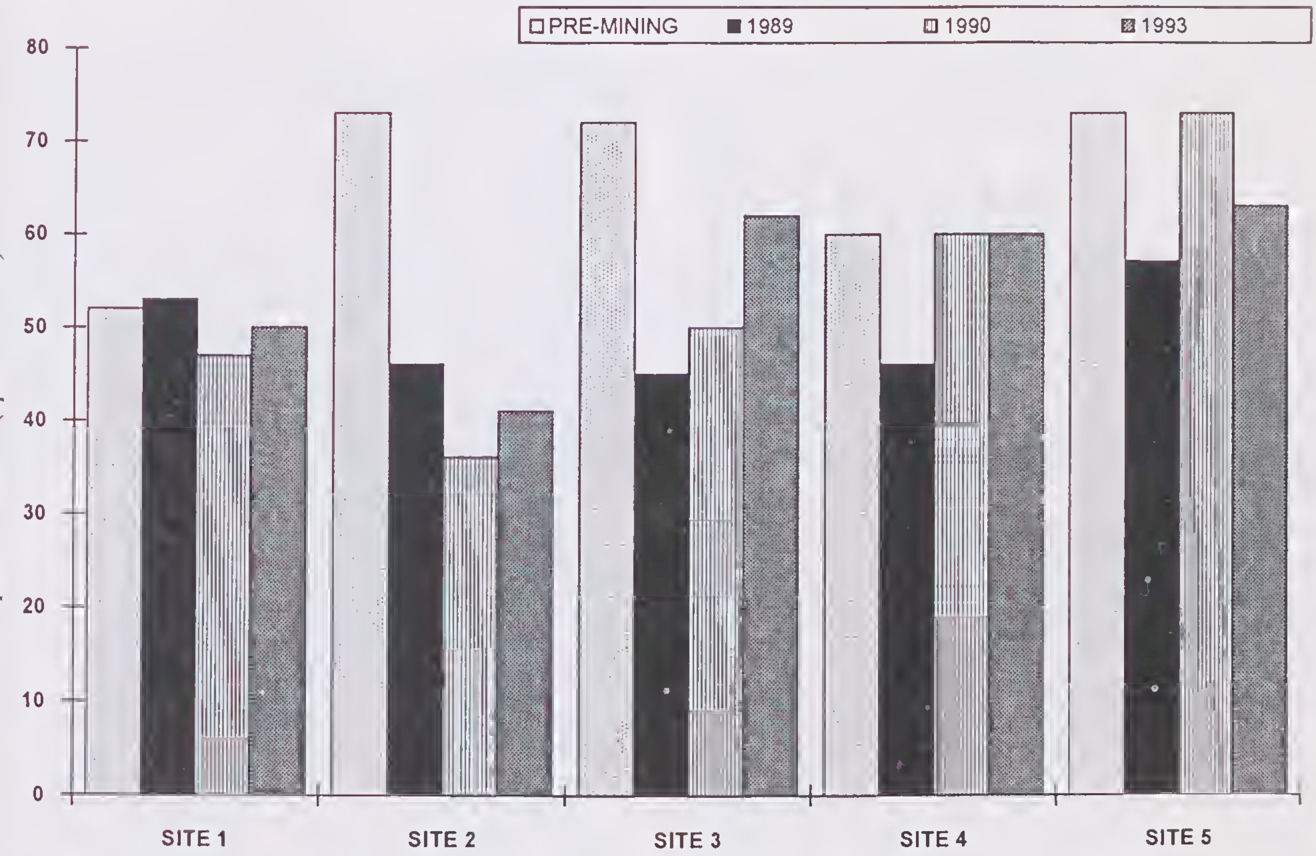

Figure 4. Species richness of five rehabilitated bauxite mined areas monitored one, two and five years after mining (Ward, *unpublished data*).

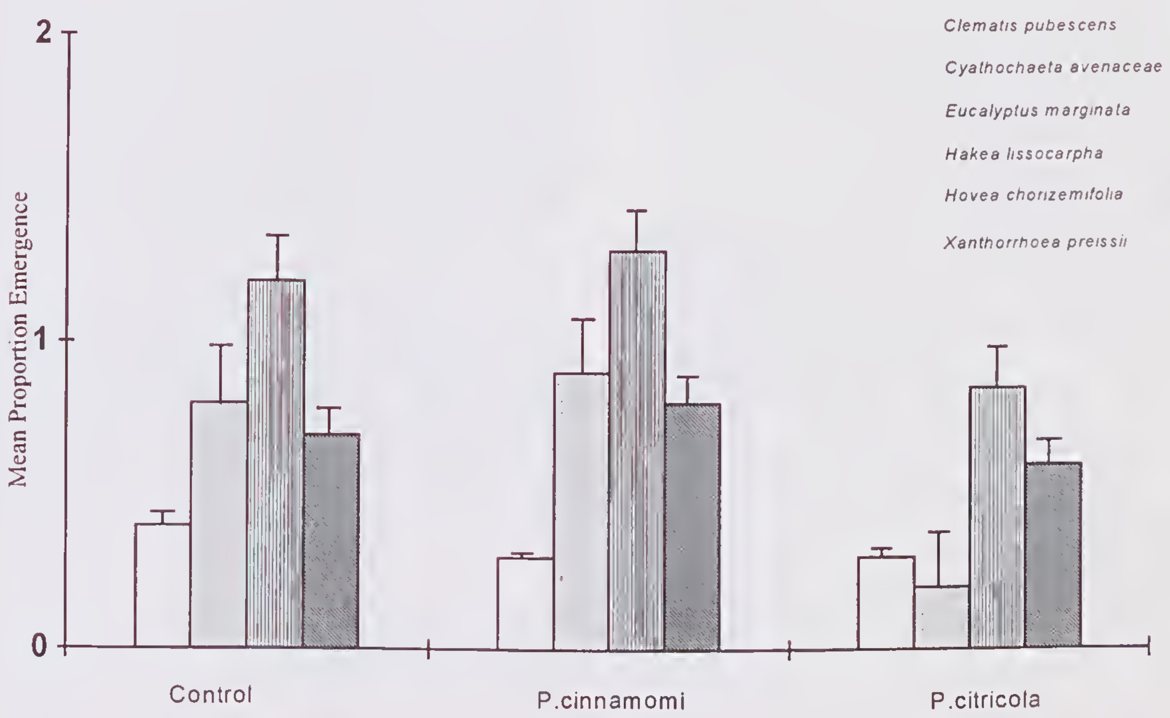

Figure 5. Mean proportion of seedling emergence of six species in a revegetated bauxite mined area monitored six weeks after seeding (from Woodman 1993). Emergence presented as least square means of arcsine transformed data with standard error bars. Seedlings C. *pubescens* and *X.preissii* were not found.

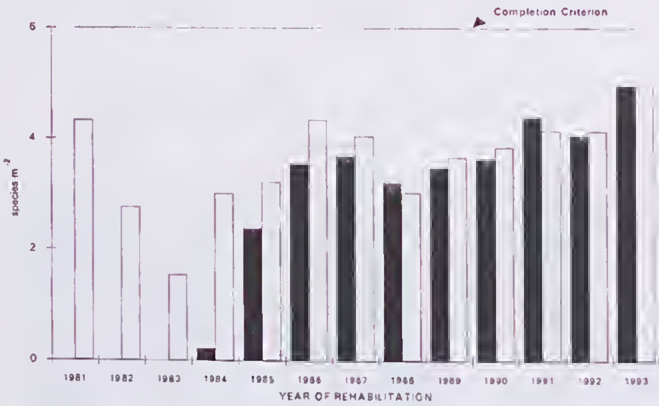

Figure 6. Mean species richness of rehabilitated mineral sands mining areas, one year after establishment and as monitored in 1993.

Establishment of high species richness

The objective of the present rehabilitation techniques for bauxite-mined areas is to establish a vegetation with a high species richness, similar to that of the adjacent forest. Some species are known to establish well from the seed present in the topsoil, other species establish from seed spread on the pits during rehabilitation. The impact of *Phytophthora* species on plant species richness is difficult to assess. Many factors affect plant establishment; plant disease is just one of many. Present levels of species richness in rehabilitated bauxite mined areas are high (Fig 5). Initiatives are underway at all mines and Alcoa's nursery to increase species richness. Very few deaths of susceptible species are found during inspections of rehabilitated areas. However, only the death of older plants, of easily observable size, would be found. *Phytophthora* species may kill the seed or the young (<6 weeks) seedlings of some species. Death at this stage would go unnoticed. Preliminary studies of six plant species found that *P. cinnamomi* had no significant (P=0.05) effect on the emergence of seedlings in two rehabilitated mined areas (Fig 6). However, *P. citricola* did significantly reduce the emergence of two species (Woodman 1993).

For RGC, the achievement of a high species richness (average of six plants per square metre) is a formal completion criterion for their revegetated mined area at Eneabba. Species richness is monitored every year. Results to date indicate that there is a consistent increase in species richness over time and that the revegetated areas are developing a richness comparable to the unmined vegetation (Fig 7). Therefore, the impact of *Phytophthora*, whilst it can be dramatic in isolated infections, does not appear to be limiting the overall success of the rehabilitation program at Eneabba.

More research and monitoring is required before the impact of *Phytophthora* species on the species richness of rehabilitated areas can be fully assessed. However, early indications are that high species richness can be obtained despite the presence of *Phytophthora* species.

Conclusion

Alcoa and RGC operate large mines in a region of Western Australia where the native vegetation is susceptible to disease caused by *Phytophthora* species. The challenge to both companies has been to develop and implement disease management programs which ensure that mining has minimal impact on the health of the native communities and the revegetated mined areas, while minimising the financial cost to the companies. The present financial cost of the programmes is significant but the results to date indicate that the disease management measures are successful. However, monitoring of their effectiveness needs to continue. Both companies accept that these costs are part of the essential costs of mining in these regions of the State, but research and development will continue to seek more cost effective disease control measures.

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